Fish Condition and Health Indices

(2005 3.c.)
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Introduction

This report contains 3 groups of analyses: 1. A summary of 2005 fish condition (the "fatness" of fish, Anderson and Neumann 1996) and health, 2. A comparison of the 2005 condition data to previous studies, and 3. A comparison of 2003-04 striped bass (*Morone saxatilis*) condition between areas and years.

Methods

2005 Sampling

Condition and health of age-0 striped bass, delta smelt (*Hypomesus transpacificus*), inland silverside (*Menidia beryllina*), and threadfin shad (*Dorosoma petenense*) were determined in 2005. Fish were collected from 2 habitat types: 1. Open channel, sampled by the Townet Survey and the Fall Midwater Trawl Survey and 2. Shallow water, sampled with a beach seine.

For condition, both fork length (FL) and standard length (SL) were measured to the nearest mm. Fish < 200 gm were weighed to the nearest 0.1 mg on a Mettler-Toledo AG-204 balance and fish >200 gm were weighed to the nearest gram. In 2005, condition of fish collected in the open channel was compared to fish collected in shallow water, with the baseline group from the open channel.

For health, fish were examined for the presence or absence of external parasites, eroded fins, gill parasites, internal parasites, and skin lesions. If a given poor health indicator was present, a value of 1 was assigned for that indicator. A chi-square test was used to determine if the frequency of occurrence was different between habitat types (Ramsey and Schafer 2002).

Historic Comparisons

Data from 3 sources was used for comparisons of the historic condition data to the 2005 data: the Suisun Marsh Study 1979-1983 (combined), the Shallow Water Predator-Prey Dynamics Study for 2001 and 2003 (combined, Predator-Prey Study), and the 2003 Length-Weight Study (LWS). The baseline condition for these comparisons was the 2005 data, both open channel and shallow water collections combined, unless otherwise indicated.

A note must be made concerning preservation method, as it can impart bias. The 2005, Suisun Marsh, and Predator-Prey studies used 10% formalin to fix and preserve specimens. Formalin is known to change length and or weight from that recorded when the fish was still living (Anderson and Neumann 1996). It may be assumed that the bias imparted by formalin was the same for all 3 studies. The LWS used isotonic salt solution (Gartz 2004) to minimize the effect of gain or loss of weight or length via osmosis. However, I was unable to account for the bias imparted by formalin or isotonic salt solution when comparing fish from the 2005, Suisun Marsh, and Predator-Prey studies to the LWS. Therefore, any comparisons with the LWS must acknowledge that some bias due to different preservation methods may influence the results.

Comparisons are by standard length and fork length, as the Suisun Marsh Study recorded standard length only and the Predator-Prey Study recorded fork length only. The LWS and the 2005 study recorded both standard and fork lengths (Table 1).

Table 1. Minimum and maximum standard length, fork length, and weight for various species, studies and habitats, as of 09/30/2005. Number significant digits are as reported by each study. Studies are: the Length-Weight Study (LWS), Predator-Prey Study (PP), Suisun Marsh (SM), and the 2005 sampling. Habitats are open channel (OC) and shallow water (SW).

Species	Habitat	Study	Min. SL	Max. SL	n, SL	Min. FL	Max. FL	n, FL	Min. wt.	Max. wt.	n, st.
Delta smelt											
	OC	LWS	21	86	192	23	94	192	0.0652	7.2297	192
	OC	2005	31.4	73.1	50	34.7	79.6	50	0.2946	6.0659	50
	SW	2005	28.3	32	2	30.6	35.4	2	0.2126	0.3042	2
	SW	PP			0	37	78	68	0.33	4.83	57
	SW	SM	51	105	55			0	1.4	16.2	55
Inland silverside											
	OC	2005	18.7	53.8	33	21.7	60.5	33	0.0633	1.4812	33
	SW	2005	18.2	87.1	118	21.1	95.8	118	0.0607	6.5758	118
	SW	PP			0	23	92	65	0.07	4.48	64
Striped bass											
	OC	LWS	14	131	241	15	148	291	0.0403	41.9730	291
	OC	2005	12.3	77.6	144	15.6	91.4	143	0.0504	9.0446	145
	SW	2005	46.2	82.9	32	53.1	96.3	32	2.0325	10.8741	32
	SW	PP			0	28	322	524	0.27	388.90	522
	SW	SSM	50	200	211			0	2.2	166.9	211
Threadfin shad											
	OC	LWS	25	128	219	28	135	219	0.2008	41.6660	219
	OC	2005	31	65.9	57	35.3	76.3	57	0.4362	6.1834	57
	SW	2005	37.8	73.4	15	41.8	78	15	0.7898	7.9226	15
	SW	PP			0	23	107	68	0.09	20.95	67
	SW	SM	37	116	39			0	0.7	36	39

Striped Bass Condition by Area

A separate analysis was carried out using data exclusively from the 2003-04 LWS (i.e., independent of the 2005 data). This analysis investigated the condition of striped bass on an intra- and inter- annual basis. The intra-annual analysis grouped striped bass by geographic area and compared condition within each year. The inter-annual analysis compared condition between the years by area.

The intra-annual analysis (within year) used the following areas, length ranges, and sample sizes. The areas were: West Suisun Bay, East Suisun Bay, Montezuma Slough, the Sacramento River, and the San Joaquin River (Figure 1). In 2003, 24-120 mm FL fish were used and in 2004, 35-101 mm FL fish. Samples sizes for 2003 by area were: West Suisun Bay (35), East Suisun Bay (35), Montezuma Slough (0), Sacramento River (38), and the San Joaquin River (126). Samples sizes for 2004 by area were: West Suisun Bay (38), East Suisun Bay (15), Montezuma Slough (27), Sacramento River (34), and the San Joaquin River (33).

The inter-annual analysis (between years) had the following areas, length range, and sample sizes. The areas were: West Suisun Bay, East Suisun Bay, Sacramento River, and the San Joaquin River. The overlapping length range was 35-120 mm FL. Sample sizes by area in 2003 were: West Suisun Bay (26), East Suisun Bay (19), the Sacramento River (28), and the San Joaquin River (105). Sample sizes by area in 2004 were: West Suisun Bay (60), East Suisun Bay (20), the Sacramento River (52), and the San Joaquin River (49).

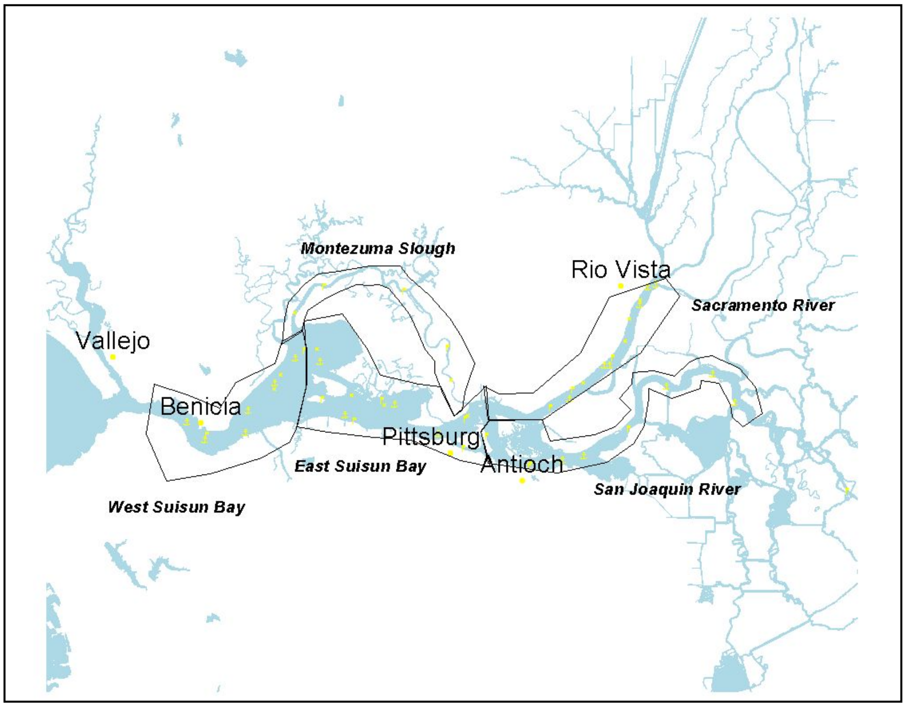

Figure 1. Areas used in the Striped Bass Condition by Area analyses.

Indicator Variable Regression for Determining Condition

I used the indicator variable regression (Freund and Littell 1991, Ramsey and Schafer 2002) to investigate "condition" between different groups of fish, by species. An indicator variable (IND) is a dummy variable that can be either 1 or 0. Each group of fish under consideration is assigned an indicator variable except the "baseline" group, in which all indicator variables are 0. The technique proceeds as follows:

The standard length-weight equation (Anderson and Neumann 1996) is linearized by taking logarithms of both sides:

$$W = a*L^b \tag{1}$$

$$\ln(W) = \ln(a) + b*\ln(L)$$

$$\ln(W) = \beta_0 + \beta_1*\ln(L)$$

Comparisons were made against this "baseline" group. An indicator variable IND and interaction variable are assign for each condition other than the baseline: IND_a and $IND_a*\ln(L)$. Equation (1) now becomes:

$$\ln(W) = \beta_0 + \beta_1*\ln(L) + \beta_2*IND_a +\ldots+ \beta_x*IND_z + \beta_3*IND_a*\ln(L) +\ldots+ \beta_y*IND_z*\ln(L) \tag{2}$$

Equation (2) tests for a significant difference between the slopes (exponent) of the baseline group and the other group(s) (so-called "slope-shift", Freund and Littell 1991). The slope evaluation occurs first (like ANCOVA, Zar 1999). If any of the coefficients for interaction (higher order) terms, $\beta_3 – \beta_y$ are significantly different from 0, a significant difference between slopes is suggested. If there is a significant difference for any given slope shift coefficient, the analysis is considered complete. The coefficients for lower order terms, (see below) are not evaluated in the presence of the higher order terms (Freund and Little 1991). The biological interpretation is that as length increases, the fractional difference in weight between the groups will increase or decrease. This condition is termed fractionally increasing or fractionally decreasing condition.

If none of the slope shift coefficients are significant, then the interaction terms are removed and the analysis repeated:

$$\ln(W) = \beta_0 + \beta_1*\ln(L) + \beta_2*IND_a +\ldots+ \beta_x*IND_z \tag{3}$$

Equation (3) tests for differences intercept (coefficient a in Equation (1)). The slope (coefficient b in Equation (1) is assumed to be the same for all length weight relationships (LWR, Le Cren 1951, Cone 1989). If any of the coefficients $\beta_2 – \beta_x$ are significantly different from 0, the interpretation is the Le Cren condition index (1951) for the group being compared with the baseline. The biological interpretation is that the difference in weight between the baseline group and the group of interest is fractionally constant in regards to length.

All testing was done at $\alpha = 0.05$. Regression was least-squares regression carried out using PROC REG run under SAS (SAS Institute, Inc. 1989). For the sake of brevity and efficiency, testing using regression is reported as “significant” or “not significant”.

Results

2005 Sampling

Delta Smelt

Only 2 delta smelt were collected in shallow water in 2005, negating a comparison between the 2 habitats. Delta smelt health was good, with only 1 fish in 50 having a poor health indicator (1 fish with internal parasites, Table 2).

Table 2. Counts and percentages of fish with various unhealthy indicators collected during in 2005, by area. Sample size (n) is in parenthesis.

		Fish counts with…				
Species	Habitat (n)	External parasites	Eroded fins	Gill parasites	Internal parasites	Skin lesions
Delta smelt						
	OC (48)	0	0	0	1	0
	SW (2)	0	0	0	0	0
Inland silverside						
	OC (30)	0	0	0	3	0
	SW (115)	0	7	0	6	1
Striped bass						
	OC (141)	0	1	1	45	0
	SW (31)	0	0	0	9	0
Threadfin shad						
	OC (54)	0	0	0	0	1
	SW (15)	0	0	0	0	0
		Fish percentages with…				
Species	Habitat	External parasites	Eroded fins	Gill parasites	Internal parasites	Skin lesions
Delta smelt						
	OC (48)	0	0	0	2	0
	SW (2)	0	0	0	0	0
Inland silverside						
	OC (30)	0	0	0	10	0
	SW (115)	0	6	0	5	1
Striped bass						
	OC (141)	0	1	1	32	0
	SW (31)	0	0	0	29	0
Threadfin shad						
	OC (54)	0	0	0	0	2
	SW (15)	0	0	0	0	0

Inland silverside

All inland silversides examined in 2005 were considered to be in good health, with a low percentage (10% or less) of fish with eroded fins, internal parasites, and skin lesions (Table 2). There was no significant difference between the frequency of fish with internal parasites by habitat type (χ^2 = 0.9348, p= 0.3336, 1 degree of freedom)

There was no significant difference in the condition of inland silversides by habitat. I used an overlapping length range of 21.7-60.5 mm FL. The lack of a significant difference in condition may be because inland silverside migrates from the littoral zone to the open channel and back on a daily basis, as observed in Clear Lake (Wurtsbaugh and Li 1985).

There was no significant difference in the condition of inland silverside based on presence or absence of internal parasites. I used an overlapping length range of 32-91 mm FL for this analysis.

Threadfin shad

Threadfin shad were also considered to be in good health in 2005, as only 1 in 59 fish had any indication of poor health (skin lesions were present in 1 fish, Table 2).

Results suggest the threadfin shad in shallow water have a fractionally increasing condition. I used all data, as the overlapping length range (41.8-76.3 mm FL) was not much smaller that the total length range (35.3-78.0 mm FL). The slope-shift coefficient was significant (Figure 2). One hypothesis is that in shallow water areas other food sources are available to threadfin shad, such as insect larvae.

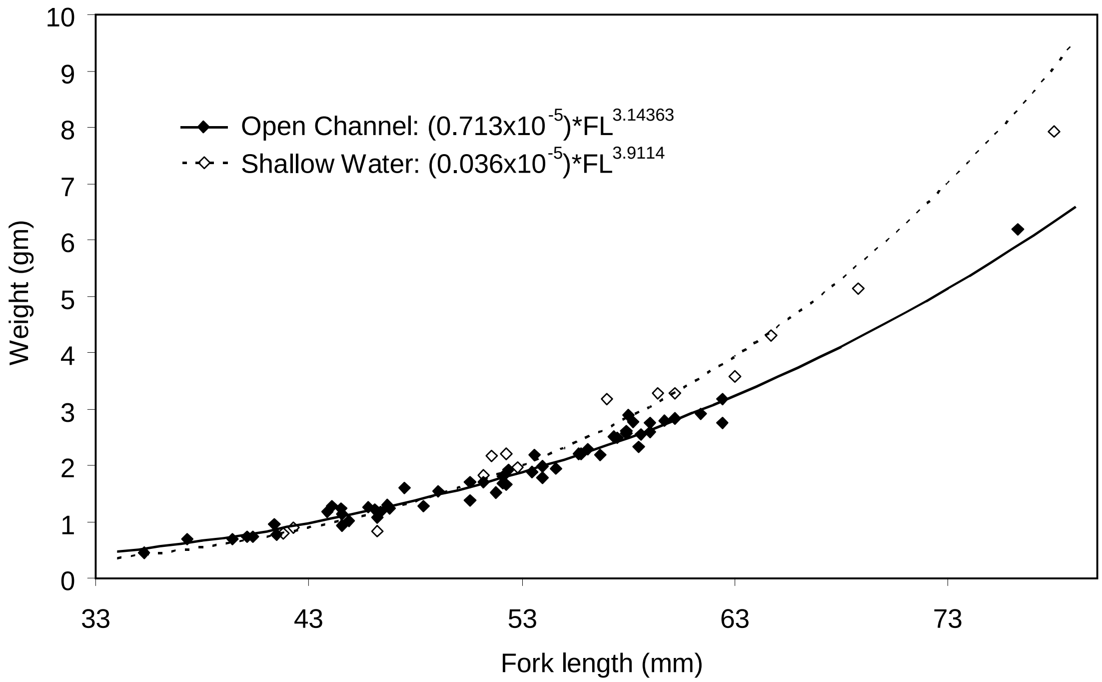

Figure 2. Length-weight data and relationships (by habitat) for threadfin shad collected in 2005.

Striped Bass

Very few striped bass had poor health indicators in 2005, except for fish with internal parasites (Table 2). Infestation by internal parasites was roughly 30% for each habitat. However, there was no significant difference in the percentage of infestation by habitat (χ^2 = 0.1326, p= 0.7157, 1 degree of freedom).

Striped bass condition was not significantly different by habitat but was based on the presence or absence of internal parasites. The analysis of striped bass condition by habitat used an overlapping length range of 53.1 and 91.4 mm FL, while analysis by presence or absence of parasites used a length range of 16.5-74.1 mm FL, as there were no observations between 74.1 and 96.3 mm FL with parasites present. Striped bass from both habitats were pooled together for the analysis based on internal parasites. Interestingly, the results suggest that fish with parasites are heavier (Figure 3). However, the fractional increase in weight is very small, as the ratio of the 2 length-weight relationships (parasites present/parasites absent), $0.634 \cdot FL^{0.10744}$, indicates. This suggests that the biological significance, if any, is small.

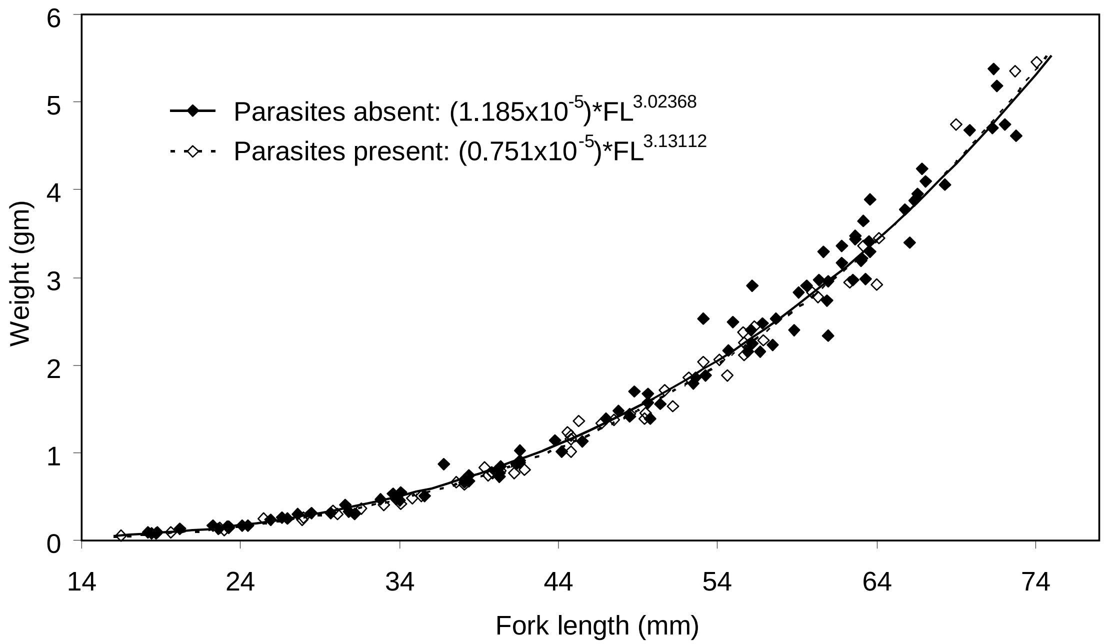

Figure 3. Length-weight data and relationships, based on presence or absence of parasites, for striped bass collected in 2005.

Historic Comparisons

Delta Smelt – Standard Length

No comparison was done for standard length. The overlapping range of lengths was from 51- 56 mm SL, as there were no observations in 2005 from 56.0 to 73.1 mm SL. I considered this range of lengths to be too small for a meaningful test.

Delta Smelt –Fork *Length*

The length range for these comparisons was 37.0-78.0 mm FL. Delta smelt from the LWS had fractionally decreasing condition while delta smelt from the Predator-Prey Study did not (Figure 4).

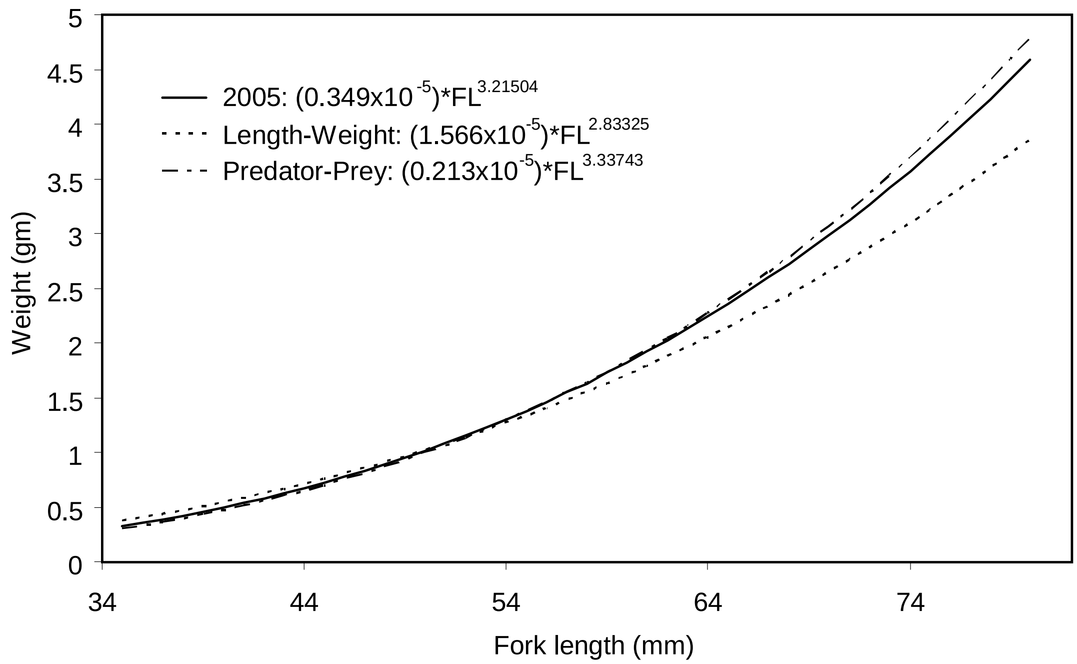

Figure 4. Delta smelt length-weight relationships from 2005 sampling, the Length-Weight Study, and the Predator-Prey Study. Data points have been omitted for clarity.

Inland Silverside – Fork Length

Given the lack of a significant difference in inland silverside condition based on habitat (see above), all fish from 2005 were combined for this analysis. No inland silverside was collected by either the LWS or the Suisun Marsh Study. The length range was 21.7-92.0 FL. Inland silverside in the Predator-Prey Study had a lower Le Cren condition index than fish from 2005 (Figure 5).

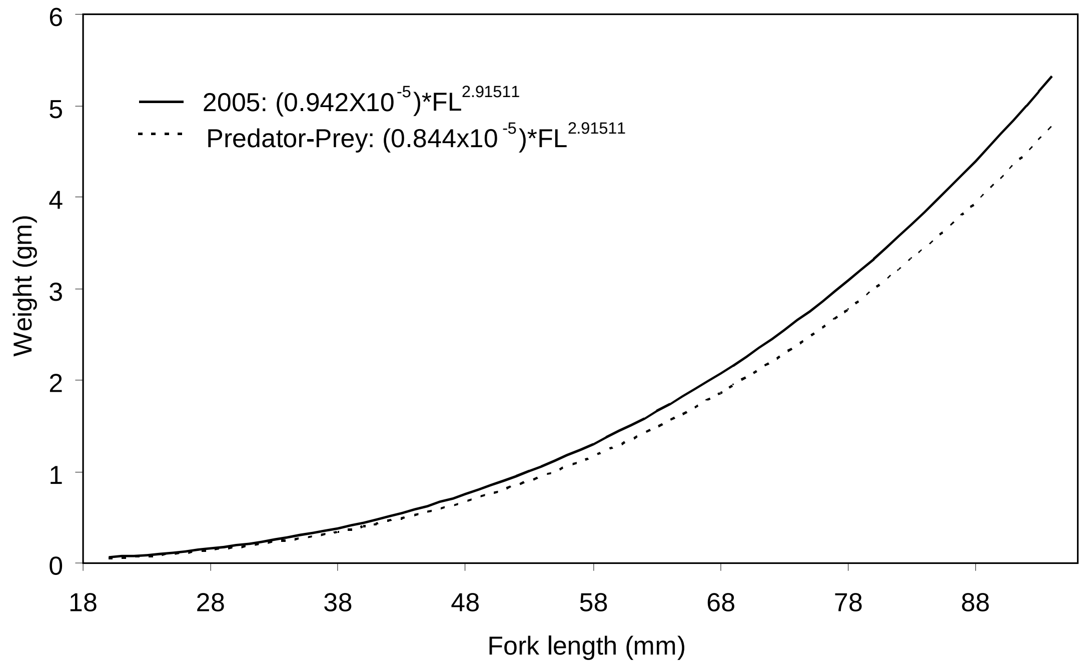

Figure 5. Inland silverside length-weight relationships from 2005 sampling and the Predator-Prey Study. Data points have been omitted for clarity.

Striped Bass – Standard Length

The striped bass length range for this analysis was 50-77.6 mm SL. I treated the 2005 data as one set and ignored the presence or absence of internal parasites, as after trimming the data to the length range there were only 9 specimens with internal parasites. In 2005, striped bass from had a higher Le Cren condition index than striped bass from either the Length-Weight Study or the Suisun Marsh Study (Figure 6).

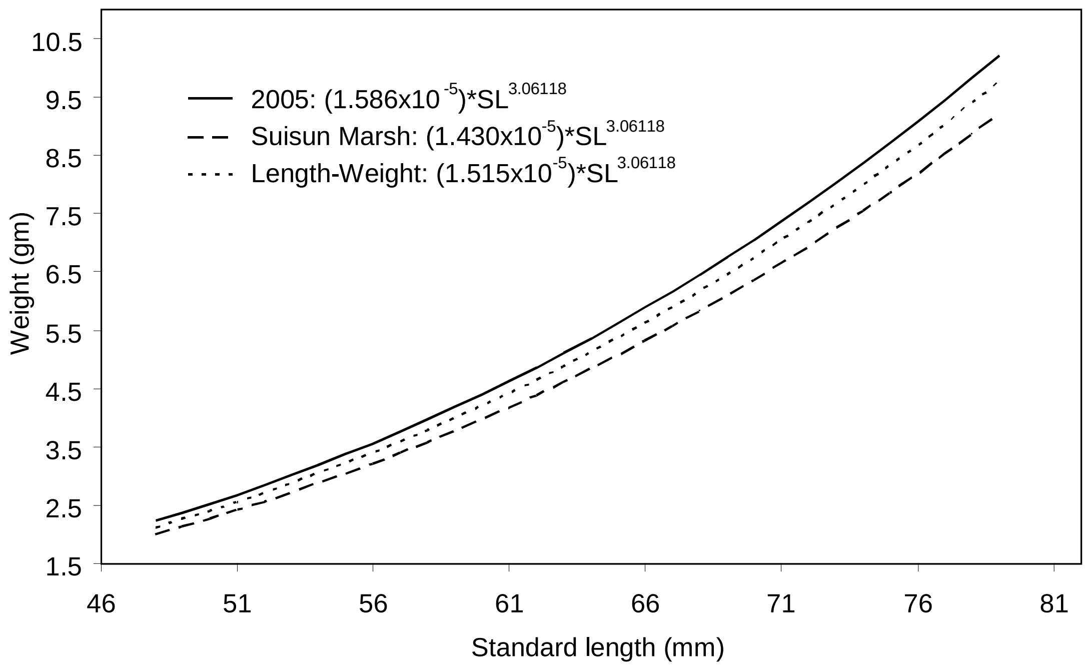

Figure 6. Striped bass length weight relationships from 2005 sampling, the Suisun Marsh Study, and the Length-Weight Study. Data points have been omitted for clarity.

Striped Bass – Fork Length

The length range for this analysis was 53.1-91.4 mm FL. To be consistent, I pooled striped bass with and without internal parasites, as was done for the standard length analysis with (see above). Striped bass from the Predator-Prey Study and the LWS both had fractionally decreasing condition when compared to striped bass from the 2005 (Figure 7).

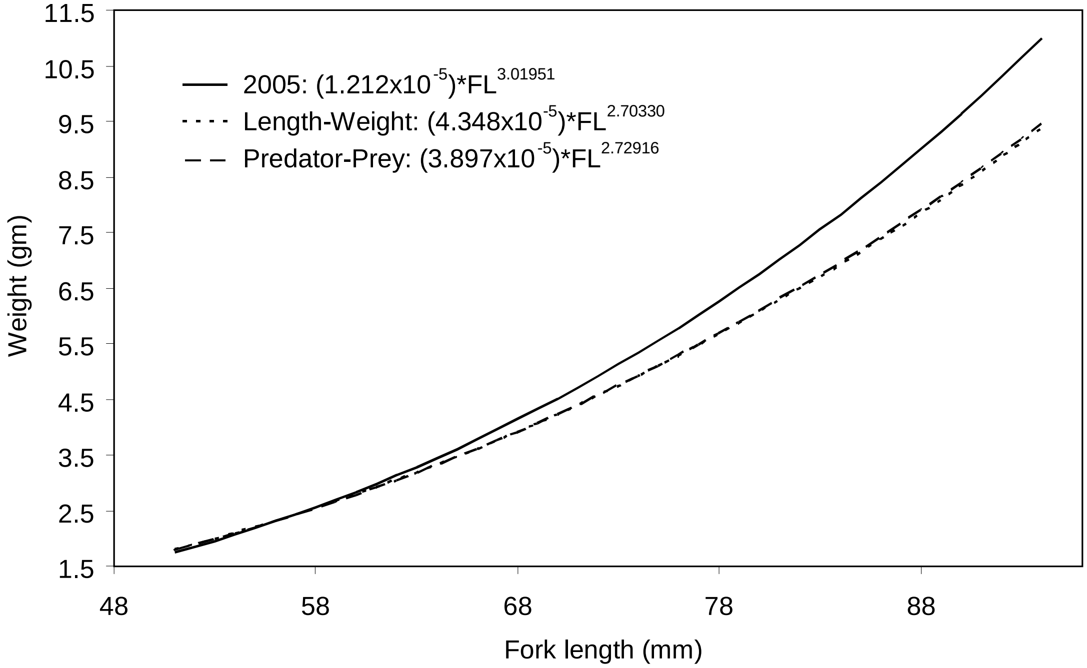

Figure 7. Striped bass length weight relationships from 2005 sampling, the Length Weight Study, and the Predator-Prey Study. Data points have been omitted for clarity.

Threadfin shad – Standard Length

The baseline group for this analysis was the 2005 open channel fish. The length range was 37.8-58.0 mm SL as the baseline group has no data from 58.0-66 mm SL. This resulted in only 12 observations in the 2005 shallow water group. In 2005, threadfin shad from shallow water had a fractionally increasing condition while threadfin shad from the Length Weight Study and Suisun Marsh Study did not (Figure 8).

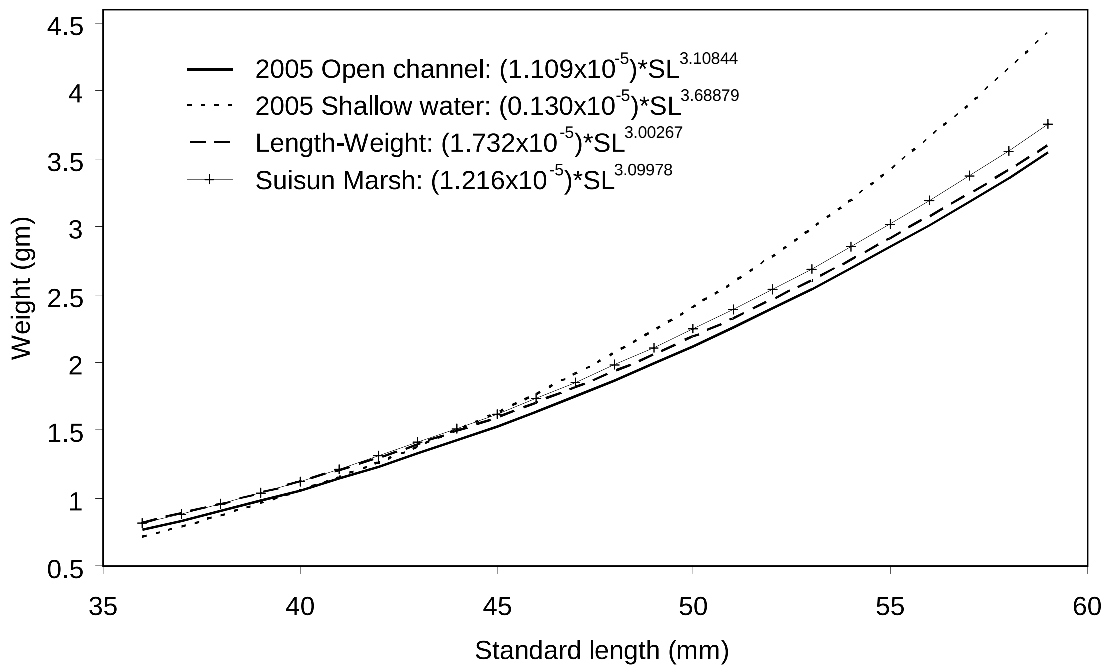

Figure 8. Threadfin shad length weight relationships from 2005 open channel and shallow water, the Length-Weight Study, and the Suisun Marsh Study. Data points have been omitted from the sake of clarity.

Threadfin Shad – Fork Length

The length range for this analysis was 41.8-76.3 mm FL, with the same baseline group as above. Threadfin shad from 2005 shallow water indicated a fractionally increasing condition while threadfin shad from the LWS and Predator Prey Study did not (Figure 9).

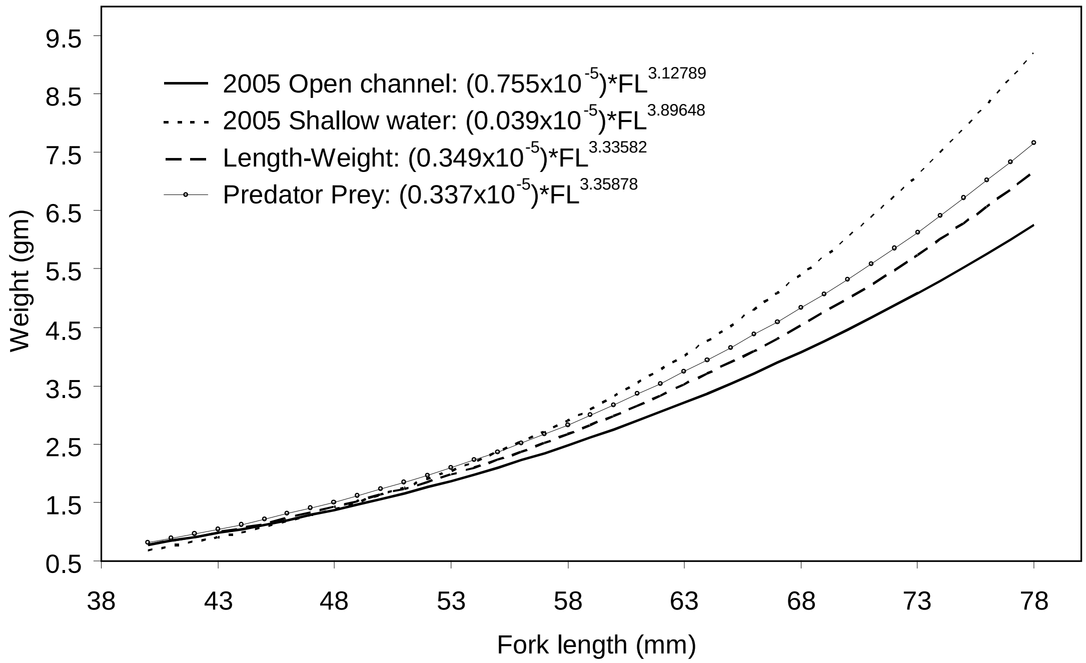

Figure 9. Threadfin shad length-weight relationships from 2005 open channel and shallow water, the Length-Weight Study, and the Predator-Prey Study. Data points have been omitted for clarity.

Striped Bass Condition by Area

Intra-Annual Analysis - 2003

Only 4 areas were used for the 2003 analysis of age-0 striped bass condition: West Suisun Bay, East Suisun Bay, Sacramento River, and the San Joaquin River, as there were no fish in the size range caught in Montezuma Slough in 2003. The baseline condition for this analysis was West Suisun Bay. In this context, East Suisun Bay, the Sacramento River, and the San Joaquin River had higher Le Cren condition indices than West Suisun Bay (Figure 10).

Defining the comparison ratio (CR) as the LWR for an area divided by the LWR for West Suisun Bay we have:

East Suisun Bay: 1.08
Sacramento River: 1.08
San Joaquin River: 1.10

The comparison ratio results suggest that condition was better upstream in 2003, but that the increase in condition was small.

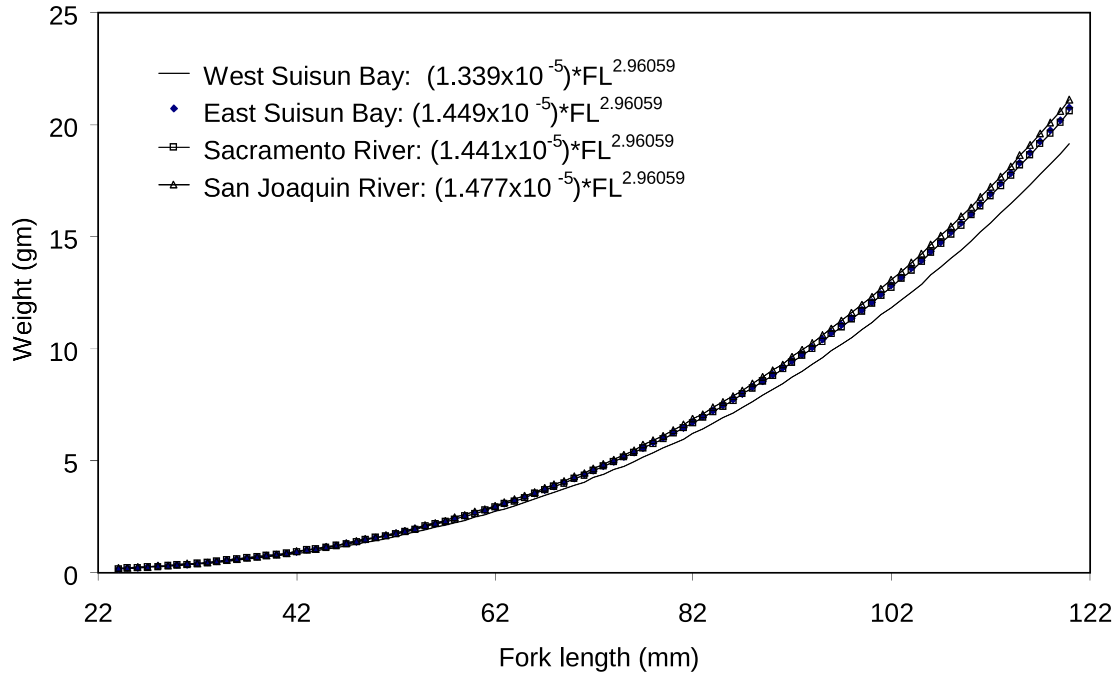

Figure 10. 2003 Striped bass length-weight relationships by area, 24-120 mm FL.

Intra-Annual Analysis - 2004

Using the same baseline and definition for CR as in 2003, results suggest that age-0 striped bass in Montezuma Slough, East Suisun Bay, and the Sacramento River had fractionally decreasing condition in relation to fish in West Suisun Bay (Figure 11). In this scenario, the fish in Montezuma Slough, East Suisun Bay, and the Sacramento River start out, on average, "heavier" but get "skinnier" as they age when referenced to fish in West Suisun Bay. The CRs for each area outside of West Suisun Bay are:

East Suisun Bay: $2.168*FL^{-0.16153}$
Montezuma Slough: $2.216*FL^{-0.16855}$
Sacramento River: $2.674*FL^{-0.21392}$
San Joaquin River: $1.081*FL^{0.00100}$

This situation is different from 2003, when condition was better upstream (see above). However, the biological significance of these results may be small, if any.

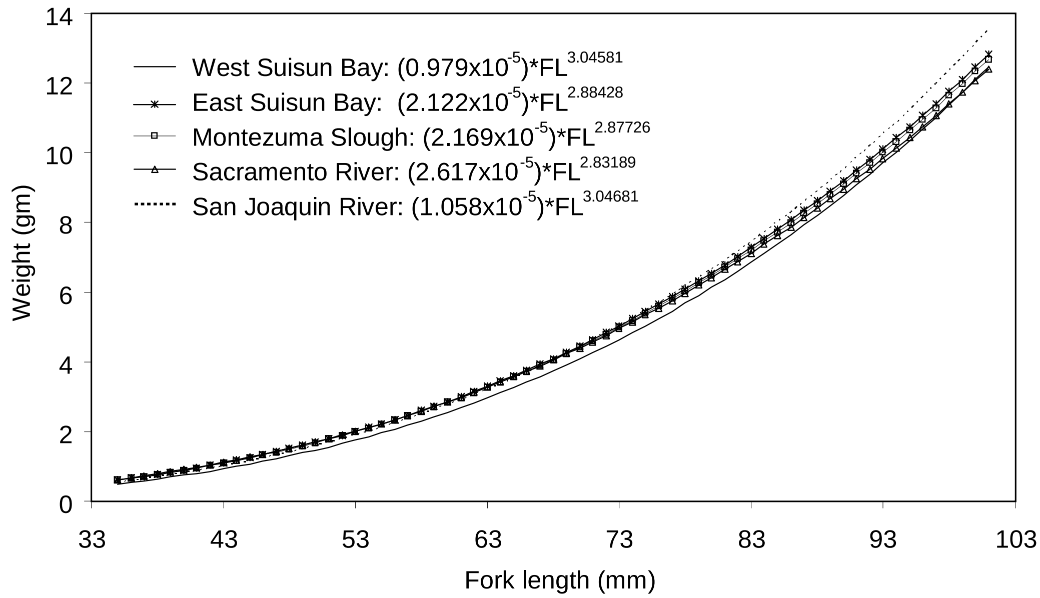

Figure 11. 2004 striped bass length-weight relationships by area, 35-101 mm FL.

Inter-Annual Analyses, by Area

West Suisun Bay and East Suisun Bay each had higher Le Cren condition indices in 2004 (Figures 12 and 13). There was no difference in inter-annual condition for the Sacramento and San Joaquin Rivers.

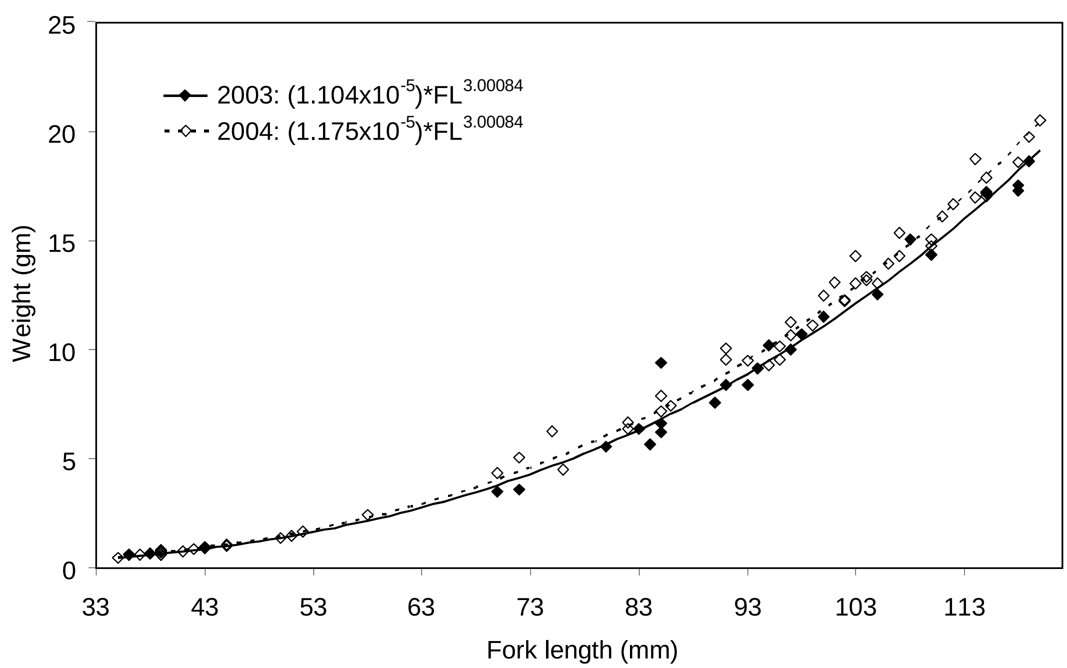

Figure 12. Striped bass length-weight relationships from West Suisun Bay for 2003 and 2004, 35-120 mm FL.

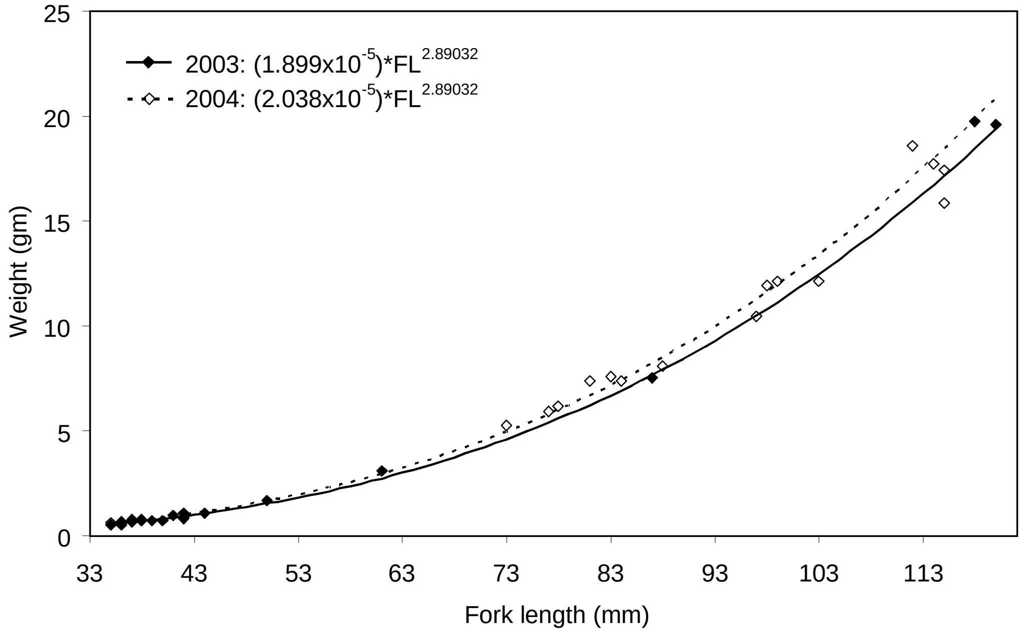

Figure 13. Striped bass length-weight relationships from East Suisun Bay for 2003 and 2004, 35-120 mm FL

Conclusions

2005 Sampling

Most fish in 2005 were in good health as far as our analytical techniques could determine. There was no difference in frequency of occurrence for internal parasites based on either open channel or shallow water habitat. Striped bass with parasites were statistically in better condition, although this difference may be biologically insignificant.

Only threadfin shad showed a difference in condition based on habitat, with threadfin shad in shallow water heavier at length. This suggests that conditions in shallow water were better for threadfin shad.

Historic Comparisons

Results suggest that fish collected in 2005 were in same or better condition than fish from the previous studies (Table 3).

Table 3. Summary of historic comparisons 2005 fish with and other studies.

	Study contrasted with 2005			
Species	Length-Weight	Predator-Prey	Suisun Marsh	2005, shallow water[1]
Delta smelt (SL)[2]	n/a	n/a	n/a	
Delta smelt (FL)	Fractionally decreasing	No difference	n/a	
Inland silverside (SL)[3]	n/a	n/a	n/a	
Inland silverside (FL)	n/a	Lower Le Cren	n/a	
Striped bass (SL)	Lower Le Cren	n/a	Lower Le Cren	
Striped Bass (FL)	Fractionally decreasing	Fractionally decreasing	n/a	
Threadfin shad (SL)[4]	No difference	n/a	No difference	Fractionally increasing
Threadfin shad (FL)[4]	No difference	No difference	n/a	Fractionally increasing

[1]Only used for threadfin shad.
[2]Length range too small for analysis
[3]No fish available for comparison with 2005
[4]Baseline condition is "2005, open channel"

Striped Bass Condition by Area

The condition of age-0 striped bass varied spatially within a given year and annually within some areas. Condition varied with length or was independent of it.

There are some concerns with this analysis. A key assumption is that the fish do not move spatially or temporally. However, this assumption could easily be violated. There are some data gaps that I did not have time to address. Although there are a number of statistically significant relationships, the biological significance, if any, is unknown. A reference group is needed for any comparison. As long as only 2 groups are being compared, one group automatically references the other. With more than one group, the case is not so simple. A size range or life stage also needs to be defined for comparison purposes.

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